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14. ABSTRACT

The SMEI has observed 88 interplanetary coronal mass ejections (ICMEs) in 2003. This work has established that most of those ICMEs, observed beyond $\sim 30°$ elongation angles, are associated with bright CMEs with appropriate speeds and position angles observed out to 30 $R_{\odot}$ in the SOHO LASCO coronagraph. However, about one quarter of the ICMEs do not have obvious candidate CME associations despite good LASCO observational coverage. We examine the characteristics of those SMEI ICMEs without LASCO CME associations to determine whether or how they differ from the other ICMEs. In particular we examine the speed profiles and brightness of those ICMEs. We discuss possible ways in which the ICMEs can arise as discrete observable structures in the interplanetary medium without being observed to any significant degree in coronagraph images.

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Interplanetary CMEs without Observed Coronagraph CMEs

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1. Introduction

The solar mass ejection imager (SMEI)[1] is designed to detect ICMEs and other transient heliospheric structures which move into the inner heliosphere. The instrument consists of three CCD cameras, each with a field of view of $60° \times 3°$, which are mounted on the Coriolis spacecraft such that they scan most of the sky every 102-minute orbit. The detectors are sensitive over the optical waveband with a response governed by that of the CCD, which is biased towards the red end of the spectrum. The region within $\sim 20°$ of Sun-centre is excluded by a baffle system. Coriolis was launched on 6 January 2003 into a Sun-synchronous polar orbit above the Earth's terminator.

Coronal mass ejections (CME) are also monitored routinely by the Large Angle Spectroscopic Coronagraph (LASCO) [2] on the SOHO spacecraft. In this paper we use observations of the SMEI transient events as a control and look for associations with LASCO events.

One of the currently unknown factors is the behaviour of ICMEs as they travel through the inner heliosphere. Despite the observation of CMEs with speeds up to 2500 km s^{-1} near the Sun, ICMEs when they reach the Earth never have such speeds. Therefore there must be significant deceleration in the inner heliosphere, at least for the fastest events. However, the well-observed event on 28-29 May, 2003 [3] appeared to have a fairly constant speed around 925 km s^{-1} thoughout its passage to 1 AU. Thus we know that some fast events, at least, appear to travel relatively unimpeded through the interplanetary medium. Detailed comparisons of events seen in both SMEI and LASCO will help us to understand better how these structures travel though the inner heliosphere.

2. The Observations

The primary data product from SMEI is an all-sky map, which we examine in an Aitoff projection in solar ecliptic coordinates with $1° \times 1°$ resolution. Some examples of the data from SMEI have been published [3,4] and the all-sky image from a typical orbit has significant exclusion areas due to the passage of the spacecraft through regions of the magnetosphere with high charged particle background, in addition to the region near the Sun itself. Some periods are also affected by high altitude auroral emission [4]. This somewhat restricted

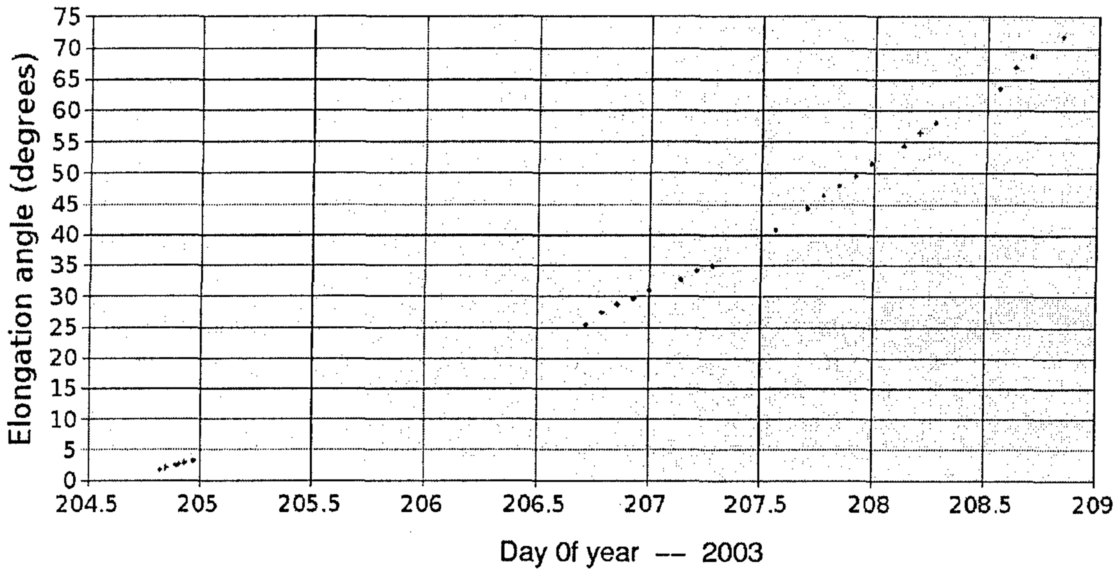

Figure 1. An event on 23-27 July, 2003 with good SMEI and LASCO correlation. The events were both observed at a position angle around 300°. Position angle is measured anticlockwise from the solar north pole.

general sky coverage means that it is only sensible to look for LASCO-SMEI associations when SMEI observes an event, rather than vice-versa.

The way we achieve this is to examine the elongation angle versus time plot for SMEI and to look for a LASCO event which occurs within at ± 12 hours of the extrapolated SMEI onset time at the Sun, assuming that the event actually left the Sun. A further requirement was that the position angle of the two events should match, and the limit to this was ± 45°. This rather large angle is intended to reflect the fact that ICMEs frequently have widths of this magnitude [5]. Figure 1 shows an example of an event where is is clear that the event seen by LASCO continued through the interplanetary medium to be seen later by SMEI. The event in LASCO is extremely faint and would not be expected to be the provenance of the SMEI event. However, the excellent match in position angle and elongation-time profile leaves little doubt that the association is real.

There were 88 mass ejection events identified in the SMEI data in 2003 [6]. (This ignores a possible 7 additional events which were questionable). Of these 4 occurred when LASCO observations were not made. Two events were ambiguous in their evolution; and 2 sets of 2 SMEI events were probably the same event. Thus there were 80 events to study. Of these 80 events 11 were totally invisible in the LASCO running difference images (the most sensitive way to examine LASCO data). To establish a null association there needed to be no LASCO event within ±12 hours of the time at which the SMEI event extrapolated back to an elongation angle of around 5°, which corresponds to 18.7 solar radii, or approximately the centre of the field of view of the outer (C3) LASCO coronagraph. The other constraint was the position angles should match. In general for positive associations this was exact, and always within a few degrees, but for null events the LASCO data was examined up to ±45°.

In Figure 2 we show SMEI images for an ICME on 17-18 April where there was no event in LASCO. The SMEI event is indicated by the arrows in each of the six images and it is at a position angle of around 15° but

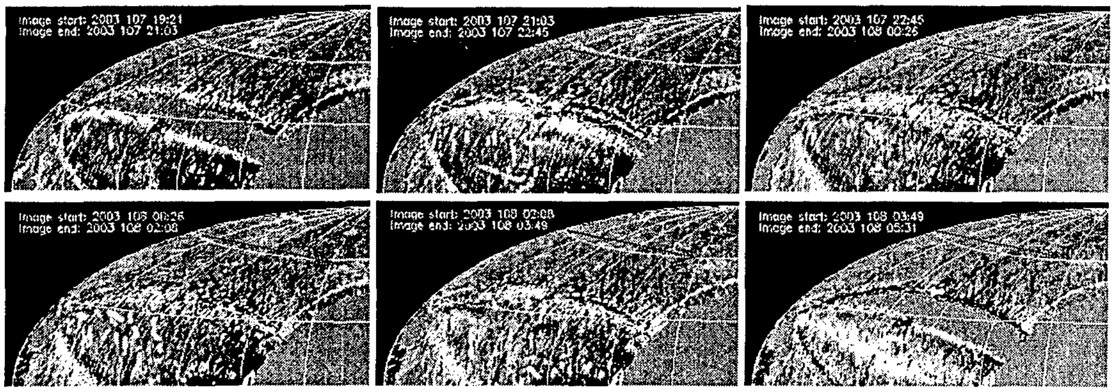

Figure 2. A sequence of SMEI images for the event seen on 17 April, 2003. The time sequence is left to right from the top. The images are the north east quadrant of the all-sky image obtained once per orbit by the SMEI cameras. The mass ejection is indicated by the arrow in each frame.

with a width of at least 30°. This event is typical of those with no LASCO association. While the event is quite difficult to see in still images, when the data is played as a movie, the event is extremely obvious.

We turn now to the 60 events which could be either reliably associated with a LASCO event with approximately the same speed, or with events which required some acceleration/deceleration in order to provide a match. It is probable that the association is unlikely for perhaps 5 of these events; however, the thrust of our study is to identify SMEI events where we are certain that nothing was visible in LASCO.

One thing that was immediately clear was that these events were not associated with any particular speed of LASCO CME. We have measured the speed of the 55 "very good" LASCO events, in the plane of the sky. We found 6 events with speeds below 300 km s^{-1}; 27 between 300 and 600 km s^{-1}; 16 between 600 and 1000 km s^{-1}; and only 6 above 1000 km s^{-1}. Thus it is evident that for a CME to be detected by SMEI it does not have to be a fast event as it leaves the Sun. This speed distribution is consistent with that reported by St Cyr et al. [5] for LASCO CMEs during the first 2 1/2 years of LASCO operation in 1996-1998.

We have also examined the brightness of these events in LASCO, and again there is no preference for the SMEI events to be particularly bright as seen by LASCO. When this is considered with the fact that around 25% of SMEI events are invisible or only associated with a very faint LASCO event, then it is clear that for an event to be seen by SMEI, it does not need to be bright in LASCO.

3. Discussion

The most significant result from this study is that there must be erupting magnetic structures on the Sun which contain little or no excess mass (over the ambient coronal density) when they pass through the LASCO field of view, which extends out to $\sim 30R_{\odot}$. These erupting structures must therefore either concentrate the mass within them at the leading edge, or more likely accumulate mass as they propagate through the inner heliosphere. One possibility is that they are associated with corotating interaction regions (CIR). These are believed to form to a significant extent inside 1 AU. [7, 8]. However, they are a low latitude phenomenon, and many of the non-LASCO events are seen near the poles (in projection). Thus it seems unlikely, but not impossible, that all the events we are seeing which do not have LASCO associations are CIRs. Also, the projected speed of a CIR

would in general be quite low in contrast to the speeds observed for the ICMEs, while we have found that those with LASCO associations are qualitatively similar to those without.

ICMEs which are more than 45° out of the plane of the sky will have an actual speed at least $\sqrt{2}$ greater than the projected speed. Thus events which are actually moving through the inner heliosphere at speeds well in excess of the solar wind speed would tend to sweep up ambient mass from the solar wind. In so doing there will be deceleration. However, evaluation of this phenomenon is beyond the scope of the current work.

4. Conclusions

1. All major events seen by SMEI in 2003 were studied.
2. Out of 88 events, 80 were at times when there was reliable LASCO data.
3. Of these 80 events, 11 had nothing visible in the LASCO data within at least ± 12 hours of the nominal extrapolation time the SMEI event left the Sun, in the quadrant of the sky that the SMEI event was observed.
4. A further 9 events were only associated with very faint LASCO candidates.

The main conclusion of this study is that erupting magnetic structures which contain little or no excess mass over the ambient corona when they are close to the Sun sweep up significant mass as they propagate through the inner heliosphere. Evidence for very faint CMEs in the LASCO data has been reported [9]. Furthermore, erupting structures which contain little or no excess mass are an important factor in a recent flare model [10] designed to address the energetics problem in major flares.

5. Acknowledgements

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